N 63-4-2

FTD-TT- 62-1092

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TRANSLATION

DESIGNING INSTRUMENTS FOR MEASUREMENTS
OF SONIC PRESSURE

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WRIGHT-PATTERSON AIR FORCE BASE

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FTD-TT-62-1892/1+2+4

UNEDITED ROUGH DRAFT TRANSLATION

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English Pages: 13

SOURCE: Russian Book, Primeneniye Ul'traakustiki k Issledovaniyu Veshchestva, Ministerstvo Prosveshcheniya RSFSR, Moskovskiy Oblastnoy Pedagogicheskiy Institut im. N. K. Krupskoy, Moskva, 1961, Vypusk XIV, pp. 129-138.

T-45
S/194-62-0-4-54-105

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DESIGNING INSTRUMENTS FOR MEASUREMENT OF SONIC PRESSURE

V. A. Kolmakov and A. I. Abrosov

Characteristics of a Sonic Field

At the present time methods of applying ultrasonic vibrations to various physicochemical processes are being widely used in laboratory work and industry. Moreover, it is important in these methods to give a quantitative evaluation of the sonic field.

The sonic field is usually characterized by its intensity, i.e., the amount of energy transmitted by the sound wave in unit time through a unit area perpendicular to the direction of wave propagation. This concept is applicable only to the field of a traveling wave. But even in this case the intensity does not completely characterize the extent of the application of ultrasound to one process or another. Not all the energy of the sound wave is absorbed by the operational volume. A part is transmitted to the walls enclosing the operational volume. In cavitation the intensity of the sound is not a satisfactory criterion to appraise the effect of the ultrasound.

In the use of ultrasound as a means of influencing various processes, the sound is usually radiated into confined operationa

volumes (Fig. 1).

Five basic types of sonic fields are possible in the confined volumes [1].

1) Free field of a plane travelling wave:

$$l, B > 10\lambda;$$
$$D > \lambda;$$
$$\alpha_m > 10l \text{ where } \alpha_s > 0{,}9,$$

where l is the height of the operational volume;

B is the diameter of the operational volume;

D is the diameter of the generator;

λ is the sonic wavelength;

α_m is the attenuation coefficient of the medium; and

α_s is the absorption coefficient of the surfaces bounding the operational volume.

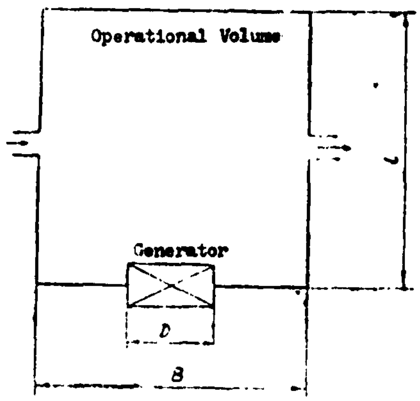

Fig. 1. Diagram of operational volume.

2) Diffuse field

$$l, B > 10\lambda;$$
$$\alpha_m < 1/3l \text{ and } \alpha_s < 0{,}2,$$

the bounding surfaces have heterogeneous roughness.

3) Plane standing-wave field:

$$B, D \ll \lambda \text{ where } B, D \gg \lambda;$$
$$\alpha_m < 1/\lambda,\ 10/l;$$
$$l \simeq n\lambda/2,\ n = 1, 2, 3\ldots;$$

the generator is loaded with a resistance which depends on the height of the operational volume (l) and the characteristics of the reflecting surfaces.

4) Pressure field:

$$l, B, D \ll \lambda;$$
$$D \simeq B;$$

rigid closed volume.

5) Acceleration field:

$$l, B, D \ll \lambda;$$
$$D \simeq B;$$

the fluid in the operational volume has one free surface.

Under actual conditions some combination of the fields just listed is observed.

All the kinds of sonic fields may be characterized by the sonic pressure. This quantity is comparatively simple to measure.

For the field of a travelling wave it is possible to convert from the sonic pressure to the intensity I using the formula:

$$I = \frac{P^2}{\rho c},$$

where P is the sonic pressure; and

ρc is the acoustical resistance of the medium.

For a rigid appraisal of the effect exerted by the ultrasoun

It is necessary to study in detail the mechanism of each concrete process which goes on during application of ultrasound. After this we can also pose the problem of measuring the physical factor or group of factors which has the decisive effect on a given process.

Instruments for Measuring Sonic Pressure

A project has been carried out at the Rostov Scientific Research Institute of Machine Construction Technology on originating a design for an instrument to determine sonic pressure in gases and liquids. The piezoelectric method based on the piezoelectric is employed to measure the sonic pressure.

An electric charge appears on the surfaces of certain substances (quartz, tourmaline, Rochelle salt, and barium titanate) when mechanical stresses are applied to them. Within certain limits there exists a proportional relationship between the value of the charge and the stress.

Thin-walled ceramic barium titanate spheres were employed as the pressure sensor. These transducer possess the advantage of being non-directional and of possessing relatively high sensitivity. The sensitivity of a radially polarized hollow sphere may be determined from formula (2):

$$E_v = \frac{E}{P} = R\,\frac{(1-2\sigma)^2}{(3-6\sigma+4\sigma^2)}\,[G_{32}(3-5\sigma)+G_{33}\sigma],$$

where E is the open-circuit emf of the receptor;

P is the sonic pressure at the surface of the sphere;

R is the outer radius of the sphere; and

σ is the ratio of the thickness of the walls to the outer diameter.

$G_{33} - 4\pi d_{33}/\varepsilon\}$ are piezoelectric

$G_{32} - 4\pi d_{32}/\varepsilon\}$ pressure constants.

For $\sigma \ll 1$; $E_V \simeq G_{32}R$.

It follows from the formula that the sensitivity of the receptor increases with an increase in the radius of the sphere. On the other hand the diameter of the receptor should be approximately five times smaller than the wave length in a given medium in order not to introduce material distortions into the sonic field.

The outer diameter of the sphere was taken in three standard dimensions: 15, 10, and 5 mm.

The upper limits of the measured frequencies for these spheres are 20, 40, and 80 kilocycles depending on their respective diameters, if the measurements are made in water, and 5, 10, and 20 kilocycles for measurements in air.

The material of the pressure transducer, in addition to barium titanate, has an additive of calcium titanate in the amount of 6% by weight of total mass.

The physical data for the piezoceramal employed is the following:

a) density ρ — 5.3;

b) piezoelectric modulus d_{33} — $3.6 \cdot 10^{-6}$ esu/d;

c) dielectric permittivity ε at $t = 10°C$, frequency $f = 1000$ cps, and a field intensity $V = 1000$ v/cm — 800;

d) dielectric permittivity ε at $t = 125°C$ (Curie's point), a frequency of 1000 cps and a field intensity $V = 100$ v/cm — 5900;

e) tangent of loss angle $\tan \delta$ at $t = 20°C$ and a frequency $f = 1000$ cps — 0.007.

As a result of the project the acoustical probe AZ-2 (Fig. 2) was designed. It consists of an electronic amplifier and three

erical pressure receptors 5, 10, and 15 mm in diameter which are alternately hooked up to the amplifier.

The amplifier serves to amplify the signal coming from the receptor to a value large enough to be registered on standard measuring instruments produced by domestic industry: vacuum tube voltmeters, frequency meters, and oscilloscopes. The MVL-3, ICh-6, and EO-7 may be recommended.

The AZ-2 is designed for measurement in a medium with a temperature from +10 to +35°C. The medium being investigated may be any gas, water, transformer oil, or weak solutions of acids and alkali.

The limits of measurable pressures are from 100 to 100,000 bars (114-174 db). The upper limit for measurements in liquids is determined by the sound level at which cavitation sets in. The range of operational frequencies is from 0.5 to 80 kilocycles for water and from 0.5 to 20 kilocycles for air.

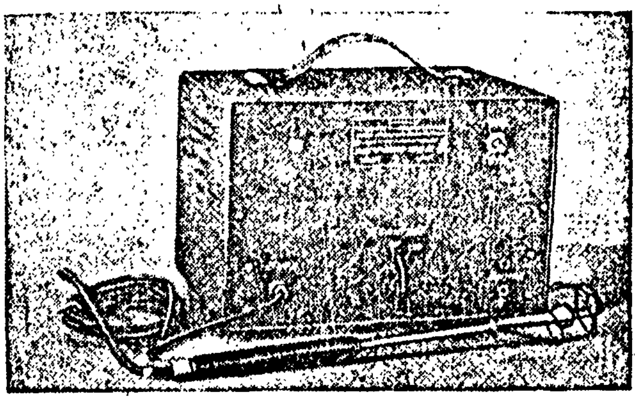

Fig. 2. Acoustical probe AZ-2.

The electronic amplifier (Fig. 3) has three stages with an overall

gain of 1000. The non-uniformity of the frequency response in the range from 0.5 to 80 kilocycles does not exceed 0.1 db with respect to the gain at 20 kilocycles.

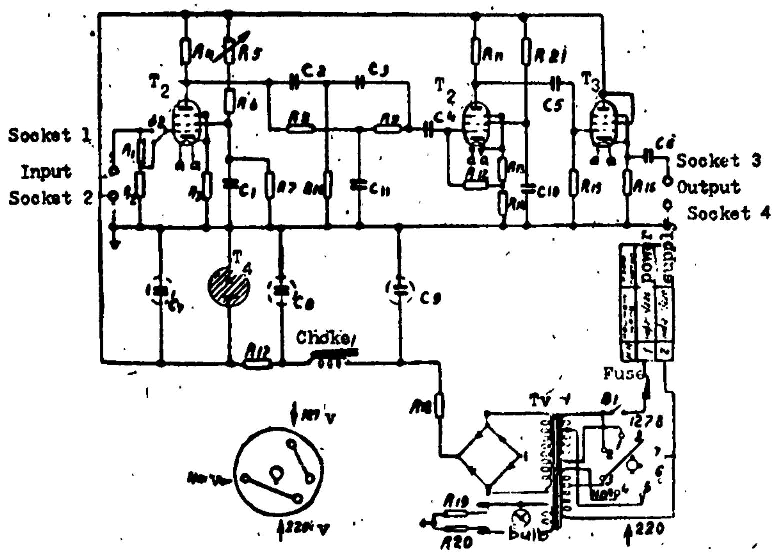

Fig. 3. Schematic diagram of AZ-2 amplifier.

The noise voltage on the output for shorted input does not exceed 8 mv.

The spherical pressure transducer consists of two hemispheres cemented together with BF-2 adhesive. The electrodes of the sound receptor are formed by a silver coating applied to its inner and outer surface.

In one of the hemispheres is a hole into which passes a flexibl wire which is soldered to the inner electrode. On the outside, the sphere is coated with a nitro dye. The field is radially polarized at a field intensity of 10 kv/cm.

The sphere holder is built in two variants. A hypodermic syr needle is used in the first variant. The sphere is soldered to t

syringe which serves as the lead from the outer electrode. The lead from the inner electrode passes inside the needle.

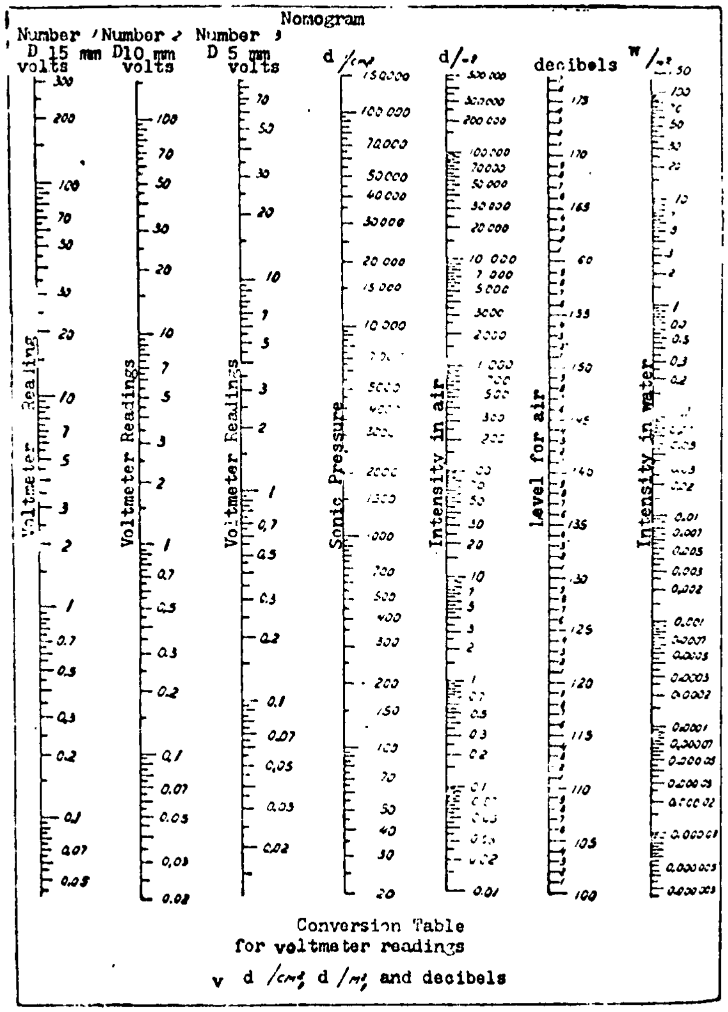

Fig. 4. Nomogram for conversion of voltmeter readings to units of sonic pressure and intensity.

In the second variant the sphere is soldered to a small brass sleeve pipe (Fig. 2). The latter is attached to a long thin brass tube with the aid of a flexible connecting element — a small rubber tube. A steel wire guard is provided for protection from mechanical damage.

The advantage of the first variant is that an almost spherical directionality pattern is preserved. The advantage of the second is that, owing to the elastic connection, mechanical stresses at the fastening point are eliminated and the error in the measurement thereby reduced.

For convenience in working with the instrument there is appended to it a nomogram (Fig. 4) for converting the readings on a voltmeter hooked up to the amplifier output to units of sound intensity. Conversion to intensity units is possible only for a travelling wave.

The next stage in this project was the creation of acoustical probe AZ-3, which makes it possible to measure the sound pressure and frequency as well as to visually observe the pressure curve on a CRT screen (Fig. 5). The AZ-3 consists of an electronic registering instrument and the same three spherical pressure receptors as on the AZ-2.

The electronic portion of the AZ-3 probe includes five units: 1) amplifier, 2) voltmeter, 3) frequency meter, 4) oscilloscope, and 5) power supply unit (Fig. 6).

The limits of measurable pressures are:

a) from 25 bars to 100,000 bars (from 102 to 174 db) in gases and from 25 bars (102 db) to the level at which cavitation sets in in liquid.

Operational frequency range:

a) from 0.5 to 20 kilocycles in gases; and

b) from 0.5 to 80 kilocycles in water.

The electronic portion of the instrument is designed to operate at an ambient medium temperature of from +10 to +35°C and at a humidity of up to 80%. The investigable media are the same as for the AZ-2.

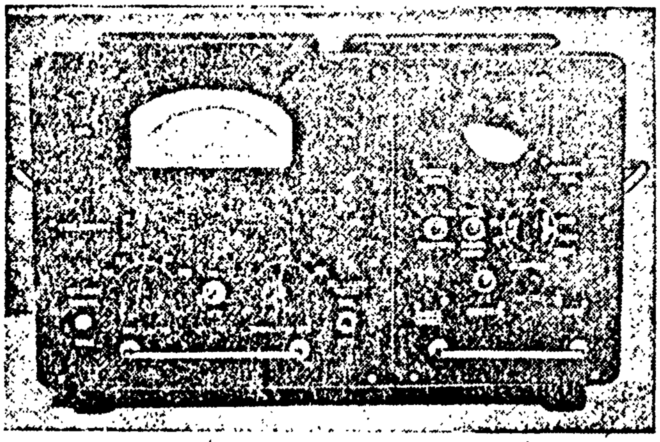

Fig. 5. Acoustical probe AZ-3.

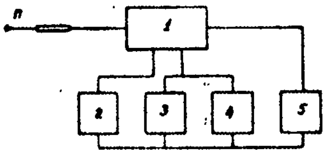

Fig. 6. Block diagram of acoustical probe AZ-3.

Calibration of Spherical Pressure Receptors

In order to calibrate the spherical pressure transducer we used the statistical method [3], which consists in the following. The barium titanate sphere is placed in some volume filled with fluid. The pressure in the volume is increased to 1.5 to 2 atm (tech.) and then quickly lowered to normal. When this is done, an electric charge occurs on the sphere electrodes by virtue of the piezoeffect. This charge is registered on a ballistic galvanometer.

$$Q = Kn$$

where Q is the charge having arisen on the sound transducer coatings;

K is the ballistic constant of the instrument; and

n is the number of divisions through which the galvanometer indicator is deflected.

The sensitivity of a pressure transducer of capacitance C is:

$$E_V = \frac{E}{P} = \frac{Q}{CP} = \frac{Kn}{CP}.$$

The ballistic constant of the galvanometer is determined with the aid of a standard capacitance C_{st} = 10,000 pf:

$$K = \frac{Q_1}{n_1} = \frac{C_{st} \cdot E_1}{n_1},$$

where Q_1 is the charge on the standard capacitor;

n_1 is the deflection of the galvanometer when C_{st} is discharged; and

E_1 is the voltage stored on the standard capacitor.

To obtain the necessary pressure in the calibration we used a hydraulic press belonging to our institute, in which certain alterations had been made: the large piston was removed and a clamping device

was designed for attaching the spheres. (The clamping device ensured the hermetic sealing of the operational volume). The pressure was measured with a manometer. The release in pressure was effected with the aid of a special valve. The ballistic mirror galvanometer GZB-47 was used as the registering instrument. The capacitance of the spherical transducer was measured on a bridge circuit at 20 kilocycles.

The sensitivities of the pressure transducer used were:

for spheres 15 mm in diameter — 2.2-2.6 μv/bar;

for spheres 10 mm in diameter — 1.4-1.7 μv/bar;

for spheres 5 mm in diameter — 0.35-0.7 μv/bar.

The self resonances of the pressure transducer and the resonances of the transducer-holder system lie within the operational frequency range.

The statistical calibration method was checked by comparison with standard spheres calibrated at the All-Union Scientific Research Institute of Physicotechnical and Radiotechnical Measurements.

* * *

The development of the AZ-2 and AZ-3 may be considered as one of the steps toward solving the problem of controlling the various processes going on under the influence of ultrasound.

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